

A Conceptual Model of Metacognitive Skills

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19961031 054

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June 1996

United States Army Research Institute for the Behavioral and Social Sciences

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**A CONCEPTUAL MODEL OF
METACOGNITIVE SKILLS**

Technical Report 51-1

U. S. Army Contract No. MDA903-93-C-0109

September, 1993

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REPORT DOCUMENTATION PAGE

**Form Approved
OMB No. 0704-0188**

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	June 1996	Final	11 Jun 93 - 11 Apr 94
4. TITLE AND SUBTITLE			5. FUNDING NUMBERS
A conceptual model of metacognitive skills			MDA903-93-C-0109 6901 C04 0605502A M770
6. AUTHOR(S) Geiwitz, J.			8. PERFORMING ORGANIZATION REPORT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Advanced Scientific Concepts, Inc. 5477 Aylesboro Avenue Pittsburgh, Pennsylvania 15217			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Institute ATTN: PERI-RS 5001 Eisenhower Avenue Alexandria, Virginia 22333-5600			10. SPONSORING/MONITORING AGENCY REPORT NUMBER Contractor Report 96-08
11. SUPPLEMENTARY NOTES Contracting Officer's Representative: Dr. T. O. Jacobs This report is published to meet legal and contractual requirements and may not meet ARI's scientific or professional standards for publication.			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Little is known about the cognitive skills used by high-level commanders and executives in problem solving. "Metacognitive" skills are abilities to monitor and direct the operation of cognitive skills. The author offers a summary of theories of metacognitive skills, including theories of intelligence, intellectual development in children and adults, and metamemory. Metacognitive skills that have been identified in the context of problem solving are discussed. A conceptual model is presented, starting with a model of problem solving and moving on to aspects of monitoring and control (technical, temporal, social, organizational). Implications for training and assessment are discussed, as well as issues of level of abstraction and how to represent the influence of metacognitive skills on human performance (flowchart vs. layered model).			
14. SUBJECT TERMS Problem solving Cognitive skills Metacognition Intelligence			15. NUMBER OF PAGES
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited

A Conceptual Model of Metacognitive Skills

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27 August 1993

Technical Report 051-1

High-level commanders and executives are expert problem solvers, but we understand very little of the nature of their expertise. We know that the executives have considerable knowledge and skill that enables them to perform their tasks in an expert manner, but we understand very little about the nature of this knowledge and these skills. The skills in particular are poorly conceptualized. We know they are not the kind of behavioral skills that psychologists have traditionally studied, such as riding a bicycle or shooting a rifle. They are "cognitive" skills; they involve manipulation and use of the elements of domain knowledge for some purpose, to some end.

A skill is defined as an ability to do something well, and a cognitive skill is thus defined as an ability to perform a cognitive task well. A cognitive task is one in which successful performance depends primarily on the possession and skillful manipulation of information and knowledge; the product of a cognitive task is usually cognitive as well — an idea, a plan, a decision, a solution to a problem. In the domain of executive performance by Army commanders, problem-solving may be considered the generic cognitive task, encompassing the formal mission-planning tasks and the less-clearly defined decision-making tasks of Army command and control.

In addition to cognitive skills, executives seem to possess even higher-level skills that enable them to use their cognitive skills effectively. Called "metacognitive" skills, these are defined as abilities to monitor and direct the operation of cognitive skills to obtain the greatest possible success. Consider the example of what is perhaps the greatest cognitive skill of humans, the ability to construct sentences to convey meaning (that is, language). Metacognitive skills in the language domain include the use of one's knowledge of grammar or the lexicon to form more effective sentences, monitoring the response of the listener to diagnose communication success, and knowing when a picture is worth a thousand words.

THEORIES OF METACOGNITIVE SKILLS

Metacomponents of intelligence. Psychological theories have conceptualized metacognition in a variety of ways. The most prominent approaches have focused on the executive-process aspect of metacognitive skills, that is, the ability to organize, sequence, and monitor cognitive processes for maximum effectiveness. Sternberg's (1984, 1985) triarchic theory of intelligence is the best example. In the componential subtheory, three types of components (intellectual processes) are defined, one of which is *metacomponents*. "Metacomponents are higher-order executive processes used in planning, monitoring, and evaluating one's

problem solving" (Sternberg, 1988, p. 132). The planning (or "legislative") metacomponents are particularly relevant to this proposal. Three important metacognitive tasks are influenced by planning metacomponents:

1. Recognizing the existence of a problem.
2. Defining the problem.
3. Formulating a strategy and a mental representation for problem solution.

Recognizing the existence of a problem sounds easy enough, but in fact it is a skill that varies considerably among people, and it is highly correlated with intelligence and creativity (Sternberg, 1988). Intelligent problem-solvers not only recognize that a problem exists, they are also better at identifying the critical problems in a domain; in the words of one researcher, they have "good taste" in problems (Zuckerman, 1983). And once they have recognized the problem, the experts define the problem in a way that makes the problem soluble. Then they formulate a strategy that promises to solve the problem, and they represent the problem mentally (or in a computer program) in a way that is close to optimal for problem solution.

Piaget's stages of intellectual development. Jean Piaget has a theory of intellectual development that can be extended to the adult years. Infants are said to be at a relatively primitive, sensory-motor stage of intellectual development that, with the onset of speech, becomes a conceptual-symbolic stage called preoperational (Flavell, 1963). Around the age of six, children enter the stage of concrete operations, in which they can apply operations (mental routines) to transform information in some way — adding two numbers to get a third, placing all red objects in the same pile. Around the age of 12, children begin the final stage of intellectual development called formal operations, in which they can apply mental routines to abstract material. For example, an adolescent can solve a problem like "If a suitcase can eat four rocks in one day, how many can it eat in two days?" Younger children cannot imagine a suitcase that eats rocks, so they will refuse to answer the question; they cannot disregard the content of the problem (its concrete aspects) and reason in a purely hypothetical way (using the form, or formal aspects, of the problem).

The advent of formal reasoning creates an interest in form, that is, adolescents become fascinated by the formal structures and processes of thought. They think about thinking, which is a good definition of metacognition. One of the products of Piaget's theory is a body of research on metacognition, much of it on memory or "metamemory"; this research will be discussed below.

Adult stages of metacognitive development. Piaget's stages have been extended to the adult years by Schaie and Geiwitz (1982). The development of formal operations suggests that metacognitive structures and strategies can be applied to direct cognition toward problem solution, a skill that continues to develop throughout adulthood. The adult stages of intellectual development reflect a general increase in metacognitive skills, which underlie adult application and use of knowledge, rather than increases in cognitive skills, which underlie childhood acquisition of basic

knowledge. The first adult stage, which occurs in young adulthood, is *temporal monitoring*, which represents the application of intelligence in situations that have profound consequences for achieving long-term-goals (involving decisions about career and marriage). Temporal monitoring is a kind of quality control process applied to problem-solving when the solutions must be integrated into a life plan that extends far into the future. It is similar to skills used by Army commanders when they prepare a synchronization matrix for the various Battlefield Operating Systems in a mission plan.

A second major application of intellect in adulthood occurs in the second adult stage, called *social monitoring*. Typically this stage develops when a family is established, and the individual must begin monitoring not only his or her own behavior, but also that of spouse and offspring. Similar extensions of monitoring skills are required, as responsibilities for others are acquired on the job and in the community. Social monitoring includes temporal monitoring of a group of people who are all working toward the same end; not only must their activities be synchronized for maximum effectiveness, but metacognitive skills such as resource allocation and the efficient division of labor among group members become primary determinants of group performance. In Gardner's theory of multiple talents, social-monitoring skills fall into the category of personal intelligence (Gardner, 1983), which includes the ability to take another person's perspective in a training situation; Anne Sullivan, the teacher of Helen Keller, is assumed to have been high in personal-social intelligence and skills. In the military domain, social monitoring is a set of metacognitive skills that will serve a commander of a combined-arms unit well.

A third adult stage of intellectual development we call *executive monitoring*. Many individuals' responsibilities become exceedingly complex. They become presidents of business firms, deans of academic institutions, officials of churches, or commanders of divisions or corps. As such, they need to understand how an *organization* works: the structure and the dynamic forces, who answers to whom, and for what purpose. They must monitor organizational activities not only on a temporal dimension (past, present, and future) but also up and down the hierarchy that defines the organization. Executive monitors must know the plans and intentions of superiors, and they must devise a structure for monitoring and controlling the implementation of policies at the lower levels of responsibility.

Metamemory. As mentioned above, Piaget's theory led to research on metacognitive skills in memory, or *metamemory*. The specific topic in which we are most interested is problem solving or what we might call *meta-reasoning*. Nevertheless, the research on metamemory is of interest, not only because it represents a productive approach to metacognitive skills, but also because it has been a developmental approach, which offers clues to the development of metacognitive skills in general.

John Flavell distinguishes between two broad areas of metamemory skills (Flavell & Wellman, 1977). The first is sensitivity to the need for planful memory. At first, the need for planful memory may be explicitly stated by a teacher or parent, who may instruct the child to remember something. Later the child may apply the metamemory skills spontaneously, knowing by now that one can prepare for later retrieval, that there is a difference between information processing for later recall and

other cognitive processing of information. The second broad area of metamemory is knowledge of variables that affect memory performance. These variables include person variables (some people have better memories, people are likely to forget information learned under emotional stress), task variables (meaningless information is harder to remember), and strategy variables (rehearsal is a good mnemonic strategy). For example, children learn that if one variable, say task difficulty, is high, predicting poor memory, they must compensate with another variable, allocating more study time. The child may test memory and then concentrate rehearsal on the unlearned items.

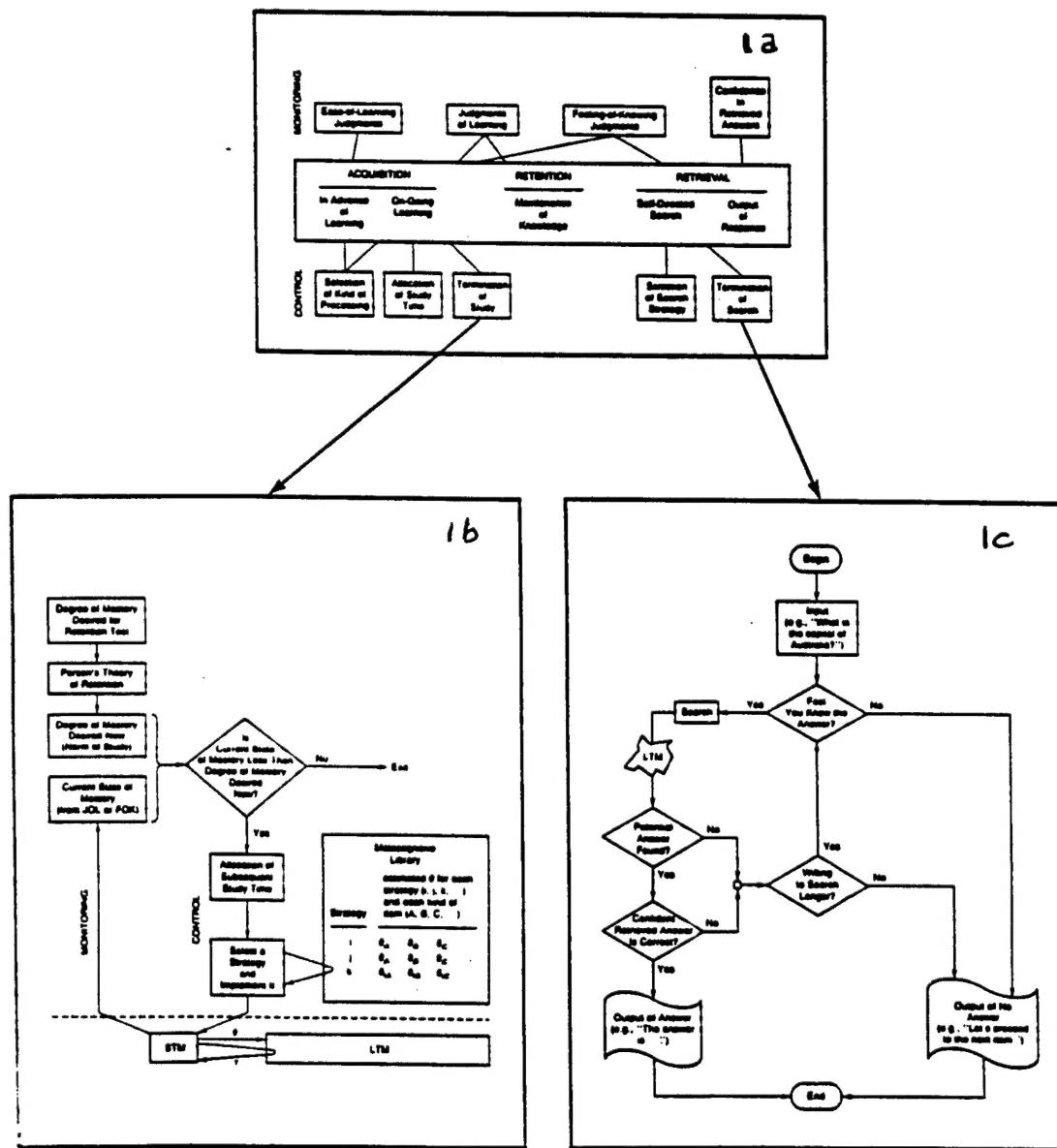


Figure 1. A theory of metamemory. (From Nelson & Narens, 1990)

Nelson's theory of metamemory, although limited to one kind of cognition, is another framework for our analysis (Nelson & Narens, 1990). Figure 1a depicts the stages of memory — acquisition, retention, and retrieval — and gives examples of both the monitoring and control functions of metamemory skills. The monitoring functions determine the control functions to be activated, as shown in Figures 1b and 1c. In Figure 1b, people are asked to learn some material to a certain criterion — "Learn this list of CIA agents perfectly, then destroy the list" — and monitors list acquisition until they make a metacognitive "judgment of learning" (JOL) or experience a "feeling of knowing" (FOK). If the JOL and FOK indicate that more study is required, control functions are activated; the kind of learning strategy is selected (rote memorization, use of mnemonic devices), and study time is allocated to the individual items on the list, according to the metacognitively perceived need. Figure 1c shows the same relations in a retrieval task, where FOK and one's confidence in retrieved answers (CRA) determines search strategy and, ultimately, termination of the search.

METACOGNITIVE SKILLS

Metacognitive skills are skills related to the effective use of cognitive skills, by using them strategically and monitoring and controlling their execution in the environment. We will focus on the cognitive skill of problem solving, a skill of significant importance to the US Army and one that is often studied in the context of metacognitive control.

The following discussion lists some of the metacognitive skills that have been identified in the context of problem solving. All of these skills — their identity, their function — are controversial, that is, there is continuing debate on all of them, and none is generally accepted. We believe each identifies at least an area of metacognitive impact, if not the precise means of influence. The purpose of our conceptual model, which itself is a "work in progress," is to clarify these skills and their interrelationships.

Detection of a problem. Does a problem exist? One metacognitive skill is the ability to detect a problem when it arises. Somehow the individual must monitor the discrepancies between the current state and the goal state, noting a problem when the discrepancies exceed a certain value.

Representation of a problem. Expert problem solvers seem to have this metacognitive skill in high degrees, and well they should, because evidence indicates that it is a critical skill for effective solutions. How an individual states the problem is a prime determinant of success in solving it.

Selection of a problem-solving method. There are many ways to solve problems. Good problem solvers know many methods, and they have the ability to select wisely, given certain characteristics of the problem domain.

Strategic application of problem-solving methods. Good problem solvers have strategies for solving the problem. They apply a potentially effective method, constantly monitoring the changes in problem state that the method produces to see if a solution has occurred. They know what they will try next, and why.

Evaluation of solution candidates. Like the wargame evaluation of the three Courses of Action selected in the mission-planning process, good problem solvers evaluate potential solutions, to see if the discrepancy between goal state and current state has been reduced.

Recognition of errors. Good problem solvers spot errors more quickly and more accurately than poor problem solvers. Common errors that result from cognitive biases and misapplied heuristics of the sort studied by Tversky and Kahneman (1974) are anticipated and guarded against.

Resource allocation. Good problem solvers, when they identify a problem, can allocate their problem-solving resources to create the most advantageous environment for the solution to the problem. If the problem requires memory, for example, they know how long it will take to memorize the material, and they allocate the time accordingly.

Temporal monitoring. Temporal monitoring includes the effective and strategic allocation of time resources, but it also includes the monitoring function, to see if the solution is developing "according to schedule." Successful managers are noted for their ability to maximize the effective use of their time (Bray & Howard, 1981). In complex problems, many resources must be synchronized for maximum impact.

Social monitoring. Problem solving in a social context — that is, *most* problem solving — is different from the same activity in isolation. Good problem solvers allocate human resources wisely, and they try to establish a social environment in which the group can function effectively. This means, among other things, they have to take personalities into account, watch for conflicts, and moderate disputes. To manage effectively they must have sensitivity and understanding of other peoples' perspectives and goals.

The social-emotional aspects of leadership became more important in American businesses as big corporations changed from family-owned enterprises controlled by autocratic individuals to publicly owned corporations led by committees. Psychologists were brought in to advise corporations on how best to solve problems in groups (Geiwitz, 1980). It was soon discovered that lack of knowledge and logic was not the chief impediment to effective group solutions; interpersonal relationships were much more crucial. One member of a committee would suggest a perfectly logical solution to a problem, but the group would reject it, because they disliked him or her. Thus, the original groups of executives brought together to learn how to solve problems — called "training groups" or "T-groups" — were soon supplanted by "sensitivity T-groups" and, later, "encounter groups." Members of these groups learned how to recognize the emotional reactions their actions provoked in other people, usually through interaction and interpretation.

Executive monitoring. Executives have key positions in a hierarchical network of individuals. To be effective problem solvers, they must understand their position in the network: their relationship with higher authorities, their relationship with subordinates, their relationship with peers. Executive monitoring is more than

temporal and social monitoring, although it includes these lesser skills. In one study, for example, the major difference between young executives and older, more experienced executives was the greater ability of the older executives to market for the company (Schaie & Geiwitz, 1982). Marketing is a very high level skill, involving knowledge of what the company is trying to do, good perception of the needs of a potential customer, and a good sense of the company capabilities to solve certain kinds of problems. It usually develops slowly over the lifespan, and many executives never become accomplished at business development.

A CONCEPTUAL MODEL OF METACOGNITIVE SKILLS

Problem Solving (A Cognitive Skill)

To develop a model of how metacognitive skills augment and facilitate the cognitive skill of problem solving, we need first a model of the problem-solving task. Complete, theory-bound models of problem solving do not exist, but the general stages and principles have been described by many; the Command Estimate is based on such descriptions. Problems are "initial states," their solutions are "goal states," and problem solving methods are means for transforming the initial state into a goal state (Newell & Simon, 1972). Problem solving in the business world (therein called management) has been described by Kepner and Tregoe (1965) and Plunkett and Hale (1982) in similar terms; the following steps are a combination of the two major managerial descriptions:

Step 1: Identify the problem. Compare actual performance with expected performance, and define the problem as the discrepancy between them.

Step 2: Describe the problem. What objects are involved? What is wrong? Where is the problem occurring? When did the problem begin? What is the extent of the problem?

Step 3: Identify the cause of the problem. Compare similar situations with and without problems. Compare affected and unaffected objects. Determine other differences between situations and objects, to identify potential causes.

Step 4: Solve the problem. Eliminate, modify, or insulate the cause of the problem so that actual and expected performance again coincide.

The Command Estimate is another general description of the problem solving process. After analysis of the mission and the orders, relevant information about the situation (including the terrain of the battlefield) and the enemy is collected, in effect identifying and describing the problem and the goal state (the mission objectives). A number of actions that might solve the problem are described — Courses of Actions (COAs). Each COA is played out, step by step, in a wargame technique and evaluated in terms of several mission objectives. One COA is recommended, but all are briefed to the commander, who makes the final decision. The Command Estimate, therefore, describes in more detail Step 4 above, suggesting that the problem solver generate

options, evaluate these options, and then choose the option with the greatest apparent likelihood of success. These skills, however, may be better considered metacognitive.

Technical Monitoring and Control

As a first approximation of a conceptual model of metacognitive skills, which we expect to evolve as library and empirical research continues, we will focus on those skills that facilitate the technical activities in problem solving. The technical aspects of problem solving comprise the purely formal operations designed to identify, represent, and solve the problem. In addition to the technical aspects, there are temporal, social, and organizational aspects of the problem-solving process, no less important in many cases; we will discuss these aspects in a later section.

Figure 2 tries to align the metacognitive skills relevant to monitoring and controlling the technical process of problem solving. This model, or submodel, looks suspiciously like a practical description of the scientific method — as it should, perhaps, since the scientific method is the best problem-solving method known to humans. Persons with a high degree of these metacognitive skills (with comparable domain knowledge) would be called experts (Laskey, Leddo, & Bresnick, 1990). Usually skilled executives or high-level commanders are expert in this sense (or were at one time, in lower-level positions), but they have other skills as well, and these skills are also pertinent to executive problem solving.

Temporal, Social, and Organizational Monitoring and Control

Technical skills, cognitive or metacognitive, are better conceptualized than temporal, social, and organizational skills, although the latter are of critical importance in the assessment and training of executive performance. What we present in this section is by no means an adequate model of these nontechnical skills, but rather a scaffolding for the later construction of such a model. We have some comments on what these models might look like, at the end of this section.

Temporal skills. As defined previously, temporal skills have to do with the effective use of time in problem solving. *Scheduling* is one such skill, one that enables the executive to allocate temporal resources effectively to complete the task in the allotted time. For example, the Army has developed the "1/3, 2/3 rule" for mission planning, that is, a commander at any echelon should use 1/3 of the total time before

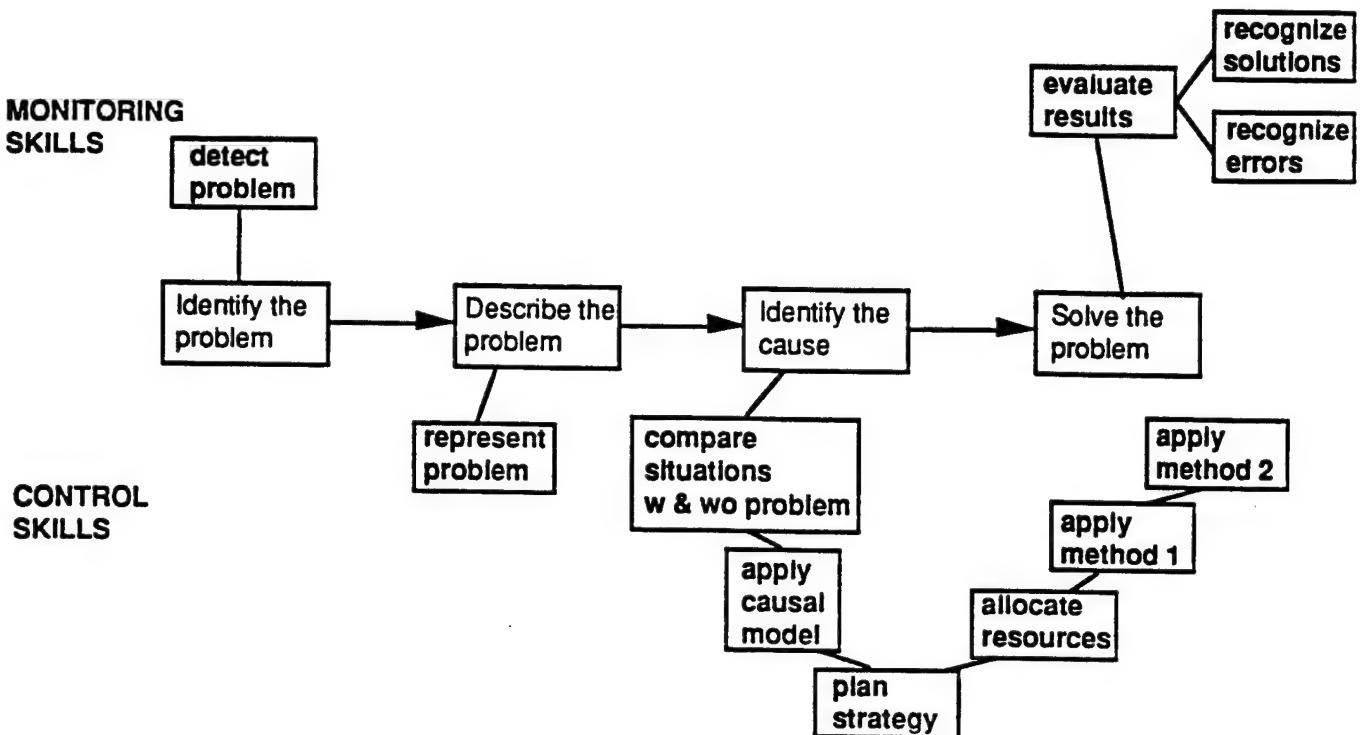


Figure 2. A model of metacognitive skills influencing technical problem solving.

the beginning of mission execution for his planning and leave 2/3 for subordinate commanders to do their planning. Another important temporal skill is *synchronization* (Long, 1989). In Army practice, tactical commanders are taught to construct a synchronization matrix (Tactical Commanders Development Course at Fort Leavenworth), in which the temporal aspects of the actions (start, stop, etc.) of each of the seven Battlefield Operating Systems (BOS) are charted, to ensure maximum impact of the operation as a whole. In most complex problem solving, several resources must be synchronized.

Social skills. Effective leaders allocate human resources wisely and delegate responsibility in a way that satisfies the technical, temporal, and organizational requirements of the task. Studies of leaderless groups show that two types of leaders typically emerge: a task leader, who facilitates the technical aspects of problem solving in a group, and a socioemotional leader, who facilitates the social aspects. There are several social skills relevant to problem solving. One is the ability to *motivate* subordinates and to use rewards (and possibly punishments) effectively. Laskey et al. (1990) speak of the importance of shared ownership, that is, an effective leader takes all points of view into account and develops a consensus in which all participants consider themselves to have contributed to. *Conflict management* is another important social skill.

Organizational skills. In a previous section, we referred to organizational skills as executive monitoring. Executives have key positions in a hierarchical network and, to be effective, must understand their position and its relationship with superordinates, subordinates, and peers. Executives must know the long-term goals

of the organization and how such goals are achieved in the context of the organizational structure. Executives are especially skilled at organizational development, which in the case of business organizations means business development; in the Army, organizational development means the creation, equipping, training, and fielding of military units, while exploring new technologies, training methodologies, and other innovations that might lead to more effective armies in the future.

The conceptual model. Temporal, social, and organizational skills are clearly important to effective executive performance, but they have rarely been modeled. Even more rarely have these metacognitive skills been modeled in the same context as technical problem-solving skills. One possibility, which we will explore, is a generic model like the one presented in Figure 2 for technical problem solving. Perhaps the same model can be used for the four different sets of metacognitive skills: technical, temporal, social, and organizational. For temporal skills, the problems would most likely have a time line — "We are going to run out of ammunition around 1600 hours." The solutions would also be time-based; in many cases, they would be scheduling solutions or synchronization solutions. Allocation of resources over time would also contribute to the solutions.

Similarly, the social skills would aid in the solution of social problems that are preventing the executive from reaching organizational goals. The technical problem may have been solved, but the executive's subordinates are reluctant to execute the solution because of fear or fatigue. The social solutions would be of the sort that reduce conflict in the group and motivate the group members to work toward the group's goals. Organizational skills would aid in the solution of organizational problems, e.g., if the organizational structure is such that no one has responsibility for certain subtasks, an organizational solution might assign such responsibility in an ad hoc fashion, to facilitate goal attainment. I am reminded of my boss on a road crew I once worked for: Working long hours in the hot summer, the workers complained of boredom and lack of motivation; they proposed that jobs be rotated, so that one day I might clean the road in advance of the seal-coating unit, the next day I might drive a packer, and the third day I might drive a gravel truck. A social motivational problem. The boss said, however, that the proposed solution could not be implemented because of a conflicting organizational problem that would arise if it were: No one worker would have responsibility for the maintenance of his piece of equipment, which we had to admit meant that the equipment would surely fall into disrepair.

TRAINING AND ASSESSMENT

The purpose of the conceptual model is to guide training and assessment of metacognitive skills in executive-level commanders. To do so, the model must include training and assessment agents and objects derived from and related to the model of the metacognitively influenced task; the model must have training and assessment modules. This section is a place holder for those modules, which will be developed during the course of the project research. As with the temporal, social, and organizational skills, we will suggest possible answers to the questions of how we can train metacognitive skills and how we can assess them in experienced commanders.

TRAINING

Most of the psychological research on metacognition has heretofore been developmental, focused on childhood changes with age and experience. This research gives some clues as to the ways such skills can be trained, but unfortunately the focus has been on when (at what age) such skills develop and what effect such skills have on children's performance (enhanced) in intellectual tasks. Case (1984), for example, describes ten levels of intellectual skill development, the last three or four of which are skills involving abstractions similar to the metacognitive processes described in the conceptual model. These skills presumably develop in the teens, with the ability to do "abstract mapping" observed in most cases between 14 and 16 years. Case says little about how these skills develop — some may require neurological development. Case does hypothesize that the limited processing capacity of humans is first devoted to basic operations and then, as these (cognitive) skills develop and require less conscious control, more of the capacity can be devoted to metacognitive, support skills. Sternberg (1984) has similar ideas, describing a process in which crude metacognitive skills (metacomponents) are used to control intellectual operations, receive and interpret feedback on the results of such operations, and refine themselves on the basis of that feedback. In Sternberg's theory, "the metacomponents form the major basis for the development of intelligence" through continual feedback loops (Sternberg, 1984, p. 172). If the metacomponents are not used to increase metacognitive skills, significant increases in intellectual performance are unlikely; mere experience or practice will not be effective.

Metacognitive skills support problem solving performance in abstract ways, providing a general framework and a general procedure. Thus, the problem solving methods described by Kepner and Tregoe (1965) and Plunkett and Hale (1982) can be taught as metacognitive skills. In such training programs, students are taught how to detect, define, and describe the problem, and then how to identify and eliminate the cause of the problem. These training programs, in a sense, teach the scientific method for problem solving. Thus, science training can be examined for clues as to how metacognitive skills can be taught. Compared to Kepner-Tregoe training, science training focuses more on the arrangement of events to determine the cause of the problem. Another focus in the scientific method is in the arrangement of events so that empirical data can be interpreted meaningfully. For example, random assignment of experimental subjects to groups for later comparisons is a preferred method, because randomization (with large numbers of subjects) equalizes all variables between groups except for the variable of interest (the independent variable). If groups are formed on the basis of preexisting characteristics (comparing men with women), the groups differ in an infinite number of ways besides the variable of interest (gender).

Can one train people to use abstract, domain-independent inferential rules to think about important events in their lives? A surprising number of theorists say no, that Plato's doctrine of formal discipline, which holds that the study of abstract rule systems trains the mind for reasoning about concrete problems, is invalid (Thorndike, 1906). Thorndike was able to show that there was very little transfer of training from one course of study (e.g., Latin) to other courses. If his view is correct, we will have little luck training metacognitive skills. But current work on this issue, exemplified by the research of Nisbett and his colleagues (Nisbett et al., 1987), suggests that abstract

skills can be taught. The primary problem in the transfer of training is in the ability of students to apply the abstract rules to specific domain content. This, the proper representation of the problem so that the abstract rule can be seen to apply, is what needs to be taught.

Specific metacognitive skills have been the substance of specific training courses, and experience of this sort also illuminates our approach to training metacognitive skills in general. For example, synchronization of resources has been trained at Fort Leavenworth for several years, in a precommand course called Tactical Commander's Development Course (TCDC). Students are taught a general methodology that can be applied to specific mission-planning exercises (Long, 1989). In essence, they are given a matrix to plan the activities of each of the seven Battle Operating Systems (BOSs) along a time line that begins before H-hour and continues into sequel missions. They are given extensive practice filling in the matrix in a variety of mission-planning exercises and encouraged to continue the practice in their command roles. Synchronization is a metacognitive skill related to temporal monitoring.

Social monitoring and control comprises a set of metacognitive skills related to team or group performance. Salas and his colleagues have been developing theory concerned with the training of teamwork skills, which has obvious implications for training metacognitive skills (e.g., Glickman et al., 1987). Findings include the fact that, for most team training, training in a team context is superior to individual training on team tasks. Also, three distinct factors appear in team training: a taskwork factor, reflecting training on the team task; a teamwork factor, reflecting learning to coordinate and communicate within the team; and a jelling factor, which reflects the ability to put the taskwork and the teamwork together in an integrated approach to problem solving in the group setting. These three factors are distinct at the beginning of training, but converge during the final stages of training. These findings bear a striking resemblance to the concept of two kinds of leadership: task leadership and socioemotional leadership.

ASSESSMENT

The first step in skill assessment is a thorough task analysis, according to the standard Instructional Systems Development (ISD) methodology (Vineberg & Joyner, 1980). If the goal is to assess a cognitive skill, one must do a cognitive task analysis. Our goal is to assess a metacognitive skill; what then is required of us? A metacognitive task analysis? Procedural or behavioral task analysis is a fairly well-defined technique (Drury et al., 1987), and even cognitive task analysis is becoming more common and more standardized (Lesgold et al., 1990). Methods for group cognitive task analysis have been developed (Salas, 1993). But I know of no work on individual or group metacognitive task analysis. Before we can begin to construct tests of metacognitive skills, we must first develop such a task-analysis methodology. The *training* of metacognitive skills also depends on such analyses.

Once the appropriate task analysis has been accomplished, the knowledge and skills (KSs) required to perform each step are determined. The KSs (not the procedural steps of the task) are the fundament of both training programs and

assessment devices. Classroom training is designed to provide the task knowledge, whereas laboratory and on-the-job training is designed to teach task skills. Verbal tests are designed to assess task knowledge and performance tests are designed to assess task skills. So the question before us is, How do we assess metacognitive skills and knowledge related to problem solving?

Cognitive task analysis uses knowledge-acquisition techniques (KATs) to elicit the knowledge and the covert decision processes involved in cognitive task performance (Geiwitz, Kornell, & M'Closkey, 1992). Many KATs also seem appropriate for the investigation of metacognitive KSs. Protocol Analysis, for example, has a domain expert "think out loud" while performing the task (Ericsson & Simon, 1984). If the expert were primed, not to describe the direct problem-solving processes, but to describe the goals of the endeavor and the strategy for goal attainment, we might elicit the metacognitive steps that monitor and control the direct processes. These steps could then be analyzed for required KSs in a conventional manner. Similarly, since effective problem representation is a key metacognitive skill, we could use the KAT called Cognitive Structure Analysis (Leddo & Cohen, 1988). (This technique grows from a conceptual model called Integrated Knowledge Structures — INKS — described by Laskey et al., 1990.) Cognitive Structure Analysis purports to identify the knowledge representations the expert uses: production rules, scripts, frames, semantic networks, or mental models. Not only would this KAT be useful in identifying the expert's representation of the problem, it might also describe the expert's overarching representation of the problem-solving process. I suspect that most scientists have a mental model of the scientific method that they use for the everyday conduct of scientific activity.

Several metacognitive skills are the subject of psychological research, and the criterion variables used to represent these skills may provide a means of assessment. Aircrew coordination and communication, for example, has been operationalized as ratings based on specific behaviors, e.g., the discussion of potential coordination problems during preflight briefings (Franz et al., 1990). Performance in games or simulations has also been used to define metacognitive skills. These games require coordination between two or more team members for superior performance (Bowers et al., 1992).

Finally, there are numerous tests available for the assessment of reasoning and problem solving ability. Tests of diagnostic ability (e.g., troubleshooting) are also available.

We should mention a special assessment technique known as Career Path Appreciation (CPA; Stamp, 1988). CPA was developed to measure the level of cognitive complexity that a member of an organization was dealing with at the present time. This level is assumed to predict later career development according to Stratified Systems Theory (Jacobs & Jaques, 1987). CPA is essentially a structured interview that focuses on a respondent's general approach to problems; it should therefore be well adapted for the assessment of metacognitive skills. However, very little information is available on the technique or on the scoring of the interview protocols.

STICKY WICKETS

Although this is a rough draft of the conceptual model, we have some confidence that our basic approach is sound and promising. I would like to mention two issues that have come up, not because they present problems or obstacles, but because they represent options that deserve further consideration before they are discarded. The first issue has to do with levels of abstraction: How many should we consider? We have described the conceptual model as if there were only two levels of abstraction: cognitive skills and metacognitive skills. But some metacognitive skills seem more abstract than others. Sternberg, for example, states, "It seems likely that the solution-monitoring metacomponent controls intercommunication and interactivation among the other metacomponents, and there is a certain sense in which this particular metacomponent might be viewed as a 'metametacomponent'" (Sternberg, 1984, p. 171). Flavell, commenting on Sternberg's theory, asks, "... are there still-more-elementary information processes that several, or even all, of his different components share in common? ... do the different components have common subcomponents?" (Flavell, 1984, p. 206). The hinting going on here seems directed toward a hierarchical network sort of arrangement, with highly abstract (generic) processes (like "solution-monitoring") towards the top and relatively concrete (domain specific) processes (like "turn screws clockwise to install") towards the bottom.

A second sticky wicket concerns the most effective way to represent the influence of metacognitive skills on human performance. We have used a flowchart approach, which has the advantage of showing precisely where in a temporal process a given metacognitive skill exerts its influence. An alternative, which has been used effectively in a variety of applications, is a layered model. Stratified Systems Theory (Jacobs & Jaques, 1987), associated with the Career Path Appreciation assessment technique discussed above, posits seven layers (levels of work) to which an executive can aspire. Each layer has different tasks; the higher layers present more complex problems, and the person attempting to solve the problems will not be able to evaluate the solution for ever increasing time spans. Thus, at the highest level, the chief executive officer of a major corporation solves exceptionally complex problems that set the company on a course of action, the success or failure of which will not become apparent for many years. People at each level depend upon the skills and knowledge of those in lower layers to implement their plans and depend upon the metacognitive activities of those in higher layers to set the goals and objectives for their relatively concrete implementations. The seven levels are further divided into three sets, defining three macrolevels: direct, organizational, and executive. We are obviously interested in the highest of the macrolevels, but SST provides a means for describing the interrelationships between the executive level and the organizational (managers) and the direct (workers and supervisors).

A similar approach, albeit for an entirely different purpose, is the Command and Control Reference Model (C²RM; Mayk & Geiwitz, 1992). C²RM is a framework for the conceptualization, design, development, and operation of intelligent C² systems, a common language for interactions that promotes open design and interoperability. Patterned after the Open System Interconnection Reference Model (OSI RM) used in the telecommunications industry, it describes interactions between one C² system and another in terms of seven layers of functions and services in each of the two interacting

systems. The seven layers are called Application, Presentation, Session, Transport, Network, Link, and Physical. The Application Layer is further sublayered, and the C²RM is primarily a definition and exposition of these seven Application sublayers. "The highest C² Application Layer is the Conflict Layer, which describes the Policies and methods used by Commanders to provide Application Services in the form of Mission statements. The second Application Layer is the Presentation Layer, which describes the Strategies and methods used by Planners to provide Application Services in the form of Plans. The third Application Layer is the Operation Layer, which describes the Tactics and methods used by Controllers to provide Application Services in the form of Tasks. The fourth Application Layer is the Procedure Layer, which describes the Schemas and methods used by Agents to provide Application Services in the form of Jobs. The fifth Application Layer is the Network Layer, which describes the Disciplines and methods used by Administrators to provide Application Services in the form of Assignments. The sixth Application Layer is the Link Layer, which describes the Techniques and methods used by Coordinators to provide Application Services in the form of Transactions. The seventh Application Layer is the Asset Layer, which describes the Instructions and methods used by Operators to provide Application Services in the form of Packages" (Mayk & Geiwitz, 1992, p. viii).

Although the C²RM is designed to describe the interactions between two C² systems — a friendly battalion and an enemy regiment, or a computerized mission planning aid such as the Army's Mission Control System and the enemy regiment — it should be effective for the description of the C² activities of a single individual — a Corps commander, for example. A human commander is, after all, a C² system and, in fact, is the precise C² system that many computerized decision aids are designed to mimic and support. The advantages of modeling executive performance with the C²RM remain to be seen, but the services and functions of each Application sublayer are clearly specified and their interrelationships worked out. The highest sublayer, the Conflict Layer, seems to have functions that are clearly metacognitive, in terms of our conceptual model, providing the overall goals and mission statements. The second sublayer, the Presentation Layer, uses strategies to construct plans for the attainment of mission objectives. Lower layers provide supporting actions. The C²RM clearly could be used to describe the influence of metacognitive skills on problem-solving performance, a possibility we will explore in parallel with the more conventional model building described in the body of this paper.

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